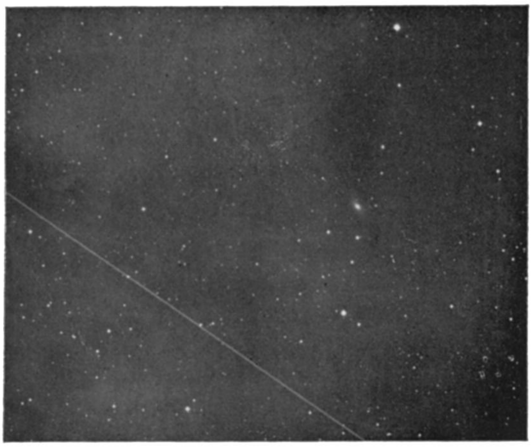

THE SMALL SPIRAL NEBULA N. G. C. 7457 AND METEOR TRAIL.
Crossley reflector, September 11, 1912; exposure two hours.

THE SPIRAL NEBULA N. G. C. 3368 AND TRAIL OF THE ASTEROID SIWA.
Crossley reflector, April 9, 1913; exposure two hours.

PUBLICATIONS

OF THE

Astronomical Society of the Pacific.

VOL. XXV | SAN FRANCISCO, CALIFORNIA, JUNE, 1913 | NO. 148

THE IRON SPECTRUM.

By KEIVIN BURNS.[1]

The astronomer has a twofold interest in the spectrum of iron. In the first place, a large percentage of the lines which have been identified in the spectra of celestial bodies are due to this element. Not only has it been discovered in the Sun and in many of the stars, but the behavior of the iron lines has told us much concerning the conditions which exist in these bodies. The progressive changes in the relative intensities of the iron lines is one of the indications of progression in spectral type. Together with those of other elements, the iron lines are leading us to understand the phenomena which are observed in sun-spots, in the chromosphere and in other parts of that star in which we are most interested. Through the effect of pressure on wave-length, we are able to form rather an accurate estimate of the pressure which exists in the reversing layer; by means of the Doppler effect we can study the circulation in the Sun, and by means of the Zeeman effect Professor HALE has found it possible to observe the magnetic and hence also the electric conditions existing in sun-spots and elsewhere on the solar surface. In all these investigations we are more or less concerned with the iron spectrum, either directly or indirectly.

For, aside from the interest attaching to the iron lines themselves, there is the fact that iron has long been used to furnish the standards with which the spectra of terrestrial or celestial sources are compared. Much of our knowledge of the radial

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velocities of the stars rests on measurements of the iron spectrum, either as terrestrial standards or as lines in the stars themselves. Hence the great amount of labor which has been spent in determining accurate values for the wave-lengths of the iron lines.

Quite recently the International Solar Union made a series of recommendations looking to the determination of a new system of wave-lengths having an accuracy sufficient for all present-day purposes. The wave-length of the red cadmium line, as determined by BENOÎT, and FABRY and PEROT, was chosen as the basis of this system. The absolute wave-length of this line was determined by counting the number of times its length is contained in that of the standard meter. This count was made by the ingenious method devised by MICHELSON, and when one realizes that it takes nearly two million waves of this length to make a meter, it becomes evident that this fundamental step in spectroscopic metrology tests the observer's fortitude and skill. Now that this wave-length has been so determined, if some calamity should cause the Paris meter to disappear, it could be replaced with an accuracy of one ten-millionth of its length, by comparing a new standard with the wave-length of the red cadmium line. In other words, the error in the wave-length of the cadmium line is not greater than one twenty-billionth of a millimeter, a quantity much beyond our imagination.

The second step in the Union's program is the determination of secondary standards by the interference method at intervals of 50 A (A = Ångstrom = 1×10^{-7mm}). The third step is the interpolation of tertiary standards at intervals of 10A by means of measures made with gratings. The iron spectrum was chosen to furnish these secondary and tertiary standards because suitable lines are found in it throughout the greater part of the region of wave-lengths which can be readily photographed. This region extends at present from about 2000 A to 9000 A. By means of Schumann plates it is possible to photograph, in vacuo, wave-lengths as short as 1000 A; and by means of dyed plates and very long exposures 10,000 A can be reached. By the phosphorescence method, 15,000 A can be photographed, but no known means enables us to photo-

graph interference rings of wave-length longer than 9000 A without resorting to impossibly long exposures. The astronomer's direct interest in spectra stops rather abruptly at 2900 A, at which point our upper atmosphere becomes opaque.

While his interest in spectra stops on the side of shorter wave-lengths at a point where the ordinary photographic plate is still sensitive, the astronomer, and also the meteorologist, is greatly concerned in the improvement of plates sensitive to the longer wave-lengths. Each of the last four decades has witnessed the introduction of better methods of photographing light to which ordinary plates are not sensitive; still it seems probable that a systematic study of the subject, by a few persons devoting all their energy to the undertaking, might accomplish as much in one year as has been accomplished in this line in the last twenty. The production of special emulsions sensitive to the infra red is receiving little attention, and no one seems to be experimenting with other emulsions than those containing a haloid of silver. No doubt plates could be made which would be at least as sensitive as those of Captain ABNEY, which no one else has as yet succeeded in making, and these might be greatly improved by the addition of a dye. A systematic search for better dyes promises very well, and this phase of the subject is receiving some attention, though not so much as it deserves. It has long been known that certain alkalies affect the sensitiveness of plates. For instance, the use of ammonia with dicyanin makes the stained plate more sensitive than one bathed with dicyanin alone, and the increase in sensitiveness is most marked in the infra red. It may be that some other chemical can be found which will prove to be better than ammonia as a stimulant to stained plates. The makers of commercial plates have only recently begun to take a great interest in red sensitive plates. It is to be hoped that color photography will stimulate the search for plates more sensitive to red light. The growing use of the neon tube as a means of illumination may also increase the demand for such plates, and plates which are very sensitive to red are likely to be somewhat sensitive to the infra red.

The work of determining secondary standards was undertaken by BUISSON and FABRY at Marseille, by EVERSHEIM at

Bonn, and by PFUND at Baltimore. The wave-lengths of lines which are to be used as standards are compared with that of the red cadmium line by the method of PEROT and FABRY. The chief feature of this method consists in measuring the diameters of the rings formed by interference when light is passed through two plane parallel plates. The plates are lightly silvered, to give the rings greater brightness. The three series of measurements mentioned above have been published for the region 4282 A – 6494 A. In part of this region the standards are farther apart than is desirable, and in the yellow-green they are lacking. BUISSON and FABRY have measured standards as far as 2373 A on the side of shorter wave-lengths, and EVERSHEIM has reached 6941 A at the other end of the spectrum. The writer has recently measured a number of lines between the limits 5434 A and 6678A. The lines in the yellow are all rather broad and unsatisfactory; many of the lines measured are fainter than standards should be, but very useful in the reduction of measures on the iron spectrum itself. In spite of the rather unsatisfactory nature of these lines, the writer considers iron better than barium or any other element which has so far been suggested for this region. The last-mentioned series is being extended to 8668 A, and one rather faint line can be measured at 8824 A. There are places between 6700 A and 8668 A where the iron spectrum does not have lines close enough together to comply with the recommendations of the Solar Union. However, this region cannot be observed with so great a dispersion nor with such accuracy as the region of half the wave-length, so we may be satisfied with those standards which can be furnished by iron.

The third step in the Solar Union's program is the determination of the tertiary standards at intervals of not more than 10 A. The Union recommended the use of large concave gratings for this step, but the work has so far largely been done by means of plane gratings. The latter gives a spectrum which is nearly linear and the former gives one which is practically normal; in either case it is extremely simple to determine the wave-lengths of other lines by interpolating between the secondary standards. The accuracy of values so determined is not very far behind that of the secondary standards themselves;

still the writer favors the determination of all standards by the interference method. Mr. St. John has taken up the work of measuring tertiary standards and he has published the wave-lengths of a number of iron lines in the region 5371 A – 6494 A, together with an estimate of their fitness to serve as standards. Dr. Goos has published measures of the stronger iron lines in the region 4282 A – 6494 A. Dr. Geiger has measured the red and infra red iron spectrum with moderate dispersion. His last line is 9809 A, but only four lines of wave-length greater than 9000 A were found. Dr. Geiger did not use the international system. Some three thousand lines in the arc spectrum of iron were recently measured by the writer at Bonn by means of a twenty-one-foot concave grating. The measures extend from 2373 A to 8824 A. By comparing the values obtained by different observers it appears that sharp lines can be measured with an accuracy of two or three thousandths Ångstrom. Whether or not spectroscopists will be satisfied with this degree of accuracy in their standards, it is at least certain that the measurements of the last few years will suffice to identify the iron lines wherever they may be found.

We might contemplate human ingenuity with a good deal of complacency when we consider that thousands of values can be measured to one five billionth of a millimeter. But if we look further we see that this uncertainty in wave-length corresponds to an uncertainty in the number of vibrations per second amounting to nearly ten billion, which shows us that there is still much room for improvement in our metrology. In other words, an error of three thousandths of an Ångstrom in the case of visible wave-length means an error in the number of vibrations per second which is over half a million times as great as the whole range of vibration frequency to which the human ear is sensitive.

In Mr. St. John's work, cited, above, he examined the lines particularly with reference to pressure effect and it is his opinion that lines which are greatly displaced by this effect should not be used as standards. This investigator found several lines which are displaced in a measurable degree by a difference of

pressure of one fifth of an atmosphere, the differenc between the density of the air at Pasadena and at Mount Wilson.

Dr. Goos made a study of the discrepancies which arise between different series of accurate measurements and in the course of this investigation he found the wave-lengths of some lines to depend on the part of the arc which served as source. By means of exposures made with a short arc as source and others for which the center of a long arc was used as source, Dr. Goos found that several lines, particularly in the green and yellow, have wave-lengths which are different near the electrodes from what they are in the center of a long arc. He finds the wave-lengths of such lines to be dependent on the conditions under which the arc burns, such as voltage, amperage, size of electrodes and their separation; and he points out that before such lines can be used as standards it will be necessary to determine minutely the conditions under which they are to be observed. In the series of measures made at Bonn it was found that the ordinary arc lines frequently have close companions in the spectra of the electrodes. There are scores of cases to be found in the ultra violet where a line which is single in the center of the arc has a companion, perhaps stronger than itself, in the electrode, the separation being two or three hundredths Ångstrom. Observations have frequently differed because one observer measured the mean of two lines and another measured only one of them. In this case the former is a measure of the electrode spectrum, the resolution being too small to separate the pair, and the latter is a measure of the spectrum of the center of the arc. This phenomenon may explain some of the shifts found by Dr. Goos. In the green and yellow the lines are not so sharp as in the ultra violet, and it is not possible to distinguish between a close companion and an unsymmetrical broadening. For investigating such cases, it is of great advantage to have no astigmatism in the spectrograph. In the green of the second order of a concave grating, the light from all parts of the arc is pretty well mixed by the astigmatism.

Of the lines measured in the iron spectrum at Bonn, about a hundred are due to impurities. Manganese, nickel and chromium furnish most of these; cobalt, calcium and copper are represented by a few lines each. An examination of the relative

intensities of these lines shows that the spectrum of an impurity in the iron arc resembles the spark spectrum of the element very closely. In this connection we recall that M. DE GRAMONT has found that the smallest trace of an impurity which will make itself known in the spectrum of another element always shows the same lines, regardless of whether the source be a hot flame, the arc, or the spark. These "last lines" in the case of some metals are enhanced lines. M. DE GRAMONT finds that these last lines are prominent in the spectrum of the chromosphere and present in the spectra of stars which have few metallic lines, viz., stars of Class B5 to A5. This would tend to show that the elements in question are present in rather small quantity, and there are other reasons for believing that this is the case. For the absorption is usually rather weak in the case of the metallic lines in the spectra of stars of early type; in the case of the chromosphere this region lies high above the level of the dense metallic layer which gives the absorption spectrum. In stellar spectra showing few metallic lines the relative intensities are more nearly those of the spark than those of the arc. This phenomenon has been explained by the assumption that these stars are hotter than those of Classes F and G, it being held that the spark is a hotter source than the arc. This theory that the spark is hotter than the arc is not borne out by the discovery by BUISSON and FABRY that the spark spectrum is produced in the arc at the tips of metallic electrodes. Neither this theory nor the one attributing the characteristics of the spark spectrum to the suddenness of potential drop is strengthened by the fact that a trace of manganese gives the spark spectrum of this element in the center of the iron arc. There is always very much less incandescent material in the spark than in the arc and this condition may play an important role in determining the relative intensities of the resulting spectral lines. In any case the results of M. DE GRAMONT and the behavior of impurities in the iron arc leads us to suspect that the quantities of the elements present may be more influential than is the temperature in determining the kind of spectrum a star will show. This consideration should stimulate, if any stimulus were necessary, the study of the spectra of mixed gases, and the study of the spectra of metals in various atmospheres.

ABSTRACTS OF PAPERS READ AT THE MEETING OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, HELD AT THE STUDENTS' OBSERVATORY, BERKELEY, CAL., ON FRIDAY, APRIL 11, 1913.

Among the papers presented at the April 11th meeting of the Society were eight by advanced students of astronomy in the Lick Observatory and the Students' Observatory at Berkeley. Six of these students—Miss WATERMAN and Miss GLANCY, and Messrs. MERRILL, KIESS, EINARSSON and HAYNES — received the degree of Doctor of Philosophy from the University of California on May 14, 1913. Their papers were the theses they presented in partial fulfillment of the requirements for this degree. Miss KIDDER's paper was the thesis presented for the degree of M. A., and Mr. LANZENDORF's the thesis presented for the degree of B. S., awarded at the same commencement. The theses for the doctorate, mentioned above, will be published later in other journals. Abstracts of the eight papers are printed here.

CLASS B STARS WHOSE SPECTRA CONTAIN BRIGHT HYDROGEN LINES.

BY PAUL W. MERRILL,
Fellow in the Lick Observatory, 1910-1913.

The normal or typical stars of Class B show only absorption lines, the characteristic lines being those of helium and hydrogen. There are known, however, nearly seventy that have bright hydrogen lines. The brightest of them, γ *Cassiopeiæ,* was discovered visually by SECCHI in 1866. Most of the other stars have been found photographically by the Harvard College Observatory. Hβ was the bright ray most frequently detected. Ordinary photographic plates are not sensitive to red light, so it remained for CAMPBELL, observing visually with the 36-inch refractor in 1894-5, to find that when Hβ is bright Hα is also bright and stronger. Both bright and dark hydrogen lines